COMPARISON OF EM AND RADIOMETRICS FOR DRYLAND SALINITY MAPPING

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Abstract

A recent technical review of mapping methods to address dryland salinity was highly adverse to methods presented by industry but promoted methods employed by the public organisations that helped produce the review. This, and the rejection of the main findings of the technical review by an independent report on dryland salinity by a House of Representatives Standing Committee on Science and Innovation, identifies a need to examine the basis for the conclusions in the technical review to determine their validity. Any false findings in the review have social and commercial as well as environmental implications as it has been presented as the definitive reference for decisions on requirements to address salinity by consumers such as catchment management groups.

The technical review identifies the level of salt store as being the mapping requirement and electro magnetics (EM) as the only means for achieving it, particularly at regional scales. It asserts, inter alia, that natural emissions of gamma radiation (radiometrics) cannot be used to map salinity and cannot provide regional results for soils. The analysis here compares results that can be expected and are achieved from EM and radiometric measurements to examine the validity of conclusions in the technical review. Results from the comparison are compared with findings of the House of Representatives salinity inquiry and used to discuss the implications for the conduct of effective science and the ability to deliver services in addressing dryland salinity.

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INTRODUCTION

The mapping of dryland salinity has recently received considerable prominence with the release of a technical review and the conduct of a parliamentary inquiry. The technical review is presented as being the definitive reference for Australia and promotes the continuation of current activities. The parliamentary inquiry sought to examine deficiencies in existing programs and identify how the delivered outcomes could be improved. The main conclusions in the reports differed dramatically. This note examines some of the differences.

Ownership of the Review of Salinity Mapping Methods in the Australian Context - Technical Report and User Guide is unclear but it was developed under the auspices of the Natural Resource Management Ministerial Council through Land and Water Australia (LWA) and the National Dryland Salinity Program with support and endorsement by the Academy of Science and the Academy of Technological Science and Engineering (available on www.ndsp.gov.au). The technical review relates to dryland salinity only and was authored by Brian Spies (CSIRO) and Peter Woodgate (Spatial Information CRC).

The content of the technical review was developed by requesting submissions on mapping methods to be presented in a specified format and then reviewing these at a public meeting organised by the academies. All speakers at the public meeting were from publicly funded organisations and none were from industry. Draft reports were then reviewed by a committee established by the academies apparently comprising personnel from publicly funded organisations.

In June 2004 the House of Representatives Standing Committee on Science and Innovation released the report entitled Science overcoming salinity: Coordinating and extending the science to address the nation's salinity problem (available on http://www.aph.gov.au/house/committee/scin/salinity/report.htm). The material in this report was obtained through a request for public submissions and the conduct of open hearings on a large proportion of these across the country. Presentations at the open hearings encompassed a spectrum of the community and included public research organisations and agencies, local communities, industry, and interested individuals. The findings received bipartisan support.

General Conclusions in the Reports

This is restricted to comparing some key points in the large reports.

The technical review promotes the continuation of mapping by public agencies to the extent of suggesting that all proposals by vendors (industry) should be vetted by the public organisations. Not only are the activities of the public organisations supported, the activities of industry are suppressed using comments such as the claims are false and have no basis in science. The House of Representatives report advocates greater industry involvement to the extent that industry should be involved in the conduct of research.

The main conclusion in the technical report is that the strategic requirement relates to the regional mapping of subsurface salt stores using airborne electro-magnetics (EM) wherein CSIRO provides commercial services in processing such data. The House of Representatives report identifies that airborne EM has never provided benefit to those involved in land management.

The assessment in the technical report is based on acceptance of the rising groundwater model as being the general model for dryland salinity as this has been adopted and promoted by publicly funded research organisations and agencies. It is identified as the model for dryland salinity on the Academy of Science web site. The House of Representatives report identifies this model as being a special case of a more general model which accords with my submission. Assessments based on an incorrect model will almost invariably be invalid.

A key assertion in the technical report is that the requirement relates to the mapping of salt stores and EM is promoted as being the only technology that can provide such information, particularly for regions. The failure to identify the significance of salt stores at different depths raises scientific issues (undefined boundary conditions). The key practical issues relate to whether the level of salt store is the only, best or relevant measure of salinity hazard or risk and whether EM provides a reliable or useful measure of the level of salt store.

The technical report asserts that airborne radiometrics cannot be used for salinity mapping. Key conclusions are:

1. Any soil mapping results using radiometrics only have local validity (the technology is not applicable to regional mapping).
2. Airborne radiometrics cannot be used to map salinity.
3. Some claims made by vendors as to the capability of radiometrics for salinity mapping have no basis in science.

The third point is apparently the basis for the recommendation that proposals for mapping by vendors (industry) should be vetted by those in public organisations.

The promotion of EM and denigration of radiometrics makes this comparison useful for addressing the applicability of the science and conclusions in the technical review.

Context

Requirements from Salinity Mapping

The basic requirements for information to be effective in addressing dryland salinity are that it should:

1. Identify the causes of adverse salinity outcomes to allow identification of appropriate remedial actions.
2. Provide the information needed to effect remediation.
3. Be in a form that can develop community capability.

The first requirement has generally been addressed with dryland salinity by stating the cause as being rising groundwater due to tree clearing and the main remediation as tree planting. There has been one official model for dryland salinity and few accepted means of remediation. The House of Representatives report concludes that this model is not generally applicable and this is illustrated here with salinity mapping results from radiometrics. Actions that do not address the cause of adverse salinity will be of limited benefit.

The second requirement relates to the need to provide information to enable action by land managers. Change can only arise through management, and the level of detail required for implementation in management is considerably greater than required for planning. The information needs extend well beyond knowledge of the occurrence of salt with knowledge of the characteristics of the soils being a prime requirement.

The third requirement relates to effectiveness.   Results will only be applied where they are understood and can readily be applied by the stakeholders. The results have to address the needs of the intended beneficiaries and this can only be ensured by developing a feedback loop to allow for continuous improvement in performance.

Presentation of Results

The information should be developed to allow presentation as discrete layers in a GIS so the results can be analysed in conjunction with other information. This requirement for combined analysis places a premium on the independent development of the different information layers to prevent conclusions arising from definition. For example, if salinity is mapped from vegetation the relationship between salinity and vegetation in the mapped information arises through definition and the GIS layers cannot be used to examine the relationship between vegetation and salinity.   It is particularly important for most applications that salinity information be derived independently from information on topography. Both EM and radiometrics can readily meet this requirement but some means of applying radiometrics do not. Mapping techniques that use multi-component analysis almost invariably do not.

THE EM AND RADIOMETRIC MEASUREMENTS

Basic Characteristics

EM

EM is generally measured as a single variable hence the measurement is one dimensional. While the measurement is one dimensional it responds to a number of factors in soils, primarily water, salt, and the nature of the soil (clay and magnetically susceptible compounds such as ion oxides). Given only one measurement and at least three prime causal factors the reason for a particular EM value cannot be determined from the measurement alone. It can take a large number of field observations to determine what the measurement is responding to in any situation.

Interpretation of the EM can sometimes be reasonably straightforward, as in the highly resistive deep sands of North Africa where airborne EM is useful for locating groundwater. Ground EM has similarly been used to monitor the level of groundwater resources in highly leached areas of Northern Australia. However, in the generally conductive surface materials across Australia the EM serves mainly to identify where field sampling would best be conducted. In practice EM results can be difficult to interpret and their significance for any purpose difficult to evaluate due to the limited information in the signal and the number of factors that affect it.

The depth of the measurement range for EM depends on factors such as height above the ground, signal frequency and the configuration of the antennae (coils). Ground measurements are needed to obtain information for shallow depths (commonly around 1, 2 and 6m due to the design of the most used instruments) with airborne data starting to provide useful information at about 10m. An airborne multi-frequency system (Tempest) provides profile information from around 10 to 150m. The depth dependence with height above the ground means that regional results can practically only be obtained for depths greater than 10m and results for soils can only be obtained using ground observations.

One distinct advantage is that the EM measurement tends to have infinite resolution hence the measurement error can effectively be independent of the intensity of the measured value and this aids analysis.

Radiometrics

Radiometrics represent the natural emissions of gamma radiation from the land surface. As currently analysed the radiometrics are four dimensional (four bands) and the measurement primarily reflects parent material and weathering. Having more measurements than unknowns theoretically allows determination of the reasons for a particular signal but there can still be confounding in the measurement as the interaction between two factors can result in the same signal arising for different reasons. Field samples are required to eliminate such ambiguities and to determine what a given signal represents. However, the greater dimensionality of the measurement and the fewer factors primarily causing the response confer great advantage when interpreting results compared with EM. There is a potential to increase this dimensionality as the measurements are normally now obtained for 256 energy levels.

Disadvantages of the measurement relate to the often poor signal to noise ratio, the spatial characteristics of the measurement, and the % measurement error depending on the intensity of the measured value. The measurement can also be influenced by additional factors, such as soil moisture. To maximise the resolution the measurement should be obtained under dry conditions. As the signal effectively derives from the soil profile the confounding effects of moisture are generally only significant in irrigation areas.

The depth of generation of the radiometric signal is the same for ground and airborne measurements and effectively declines exponentially with depth. While around 70% of the signal generally derives from the surface 30 cm much of the signal usually derives from greater depths, up to around 1m. However, the signal that develops at the surface depends on the underlying materials and the data can be used to identify deep geological structures such as fault lines and fractures. Effective interpretation of the signal requires reference to the entire soil profile and not just the surface soil. The independence of the depth of the signal generation with the measurement height allows use of airborne measurements for local as well as regional mapping.

The characteristics of the radiometric measurement mean that it is not simple to comprehend or analyse. However, the dimensionality and number of causal factors make it much easier to relate to field observations than EM (fewer field measurements are required). With correctly implemented studies the results are much simpler to comprehend and apply then EM as they contain MUCH more information.

Obtaining Results

EM

The EM measurement is easy to take and apply surface fitting routines to produce a cohesive (good looking) image. The image is apparently easy to interpret in simply showing highs and lows. The difficulties arise in attempting to determine what causes the variations. The amount of archival EM data is very limited as it has only been acquired for detailed mineral exploration studies and to address salinity.

The technical review uses a pers. comm. from Baden Williams to justify the claim that EM is measuring the level of salt store. Given the use of EM for salinity mapping in Australia for around 20 years one is left to question why the reliance on a personal communication.

The answer is given by other comments in the technical review where it is noted that correlations have been established between the level of salt in a profile and the EM measurement but that the correlations differ between areas. There is no absolute calibration of an EM instrument whereby it provides a direct measure of the level of salt which is inevitable due to the number of factors that affect the measurement. The measurement must be empirically correlated for each situation.

Few people drill to the 6m depth required to interpret EM31 results because of the expense. The practical response is to use EM to identify changes and use field sampling to determine what is occurring at apparent key locations. EM is used to reduce the need for field sampling by identifying targets. This can be time consuming and costly but is generally reliable and is how EM has been used in mineral exploration. Field costs when interpreting airborne EM measurements are much higher than for ground EM due to the deep sampling depths.

Radiometrics

Data acquisition is more difficult than for EM and the data are difficult to analyse and produce a cohesive map. An extensive data archive exists but old survey data are generally of low quality and often have to be re-grided before analysis to produce a useful result.

Visual analysis can be used to identify general information such as geological formations but numerical analysis is needed to extract detailed information relevant to soils and salinity. Field observations are used to identify what the detail represents hence interpretation generally depends on empirical correlation. An appreciable number of field samples may be required for reliable interpretation (around 100 to150 for a regional soil survey) and the methodology must be designed to remove ambiguities arising from the interaction between parent material and weathering. However, the shallow sampling depth (generally to around 0.6m) makes it feasible to obtain the necessary field observations. Costs can be reduced and technology transfer promoted by training stakeholders (e.g. farmers) to obtain the soil samples.

Despite these constraints useful maps can be produced at much lower cost for regions than by any other method. The maps contain much more information on soil properties than provided by other methods and at higher spatial detail where salinity is one of the soil properties that can be mapped. The maps can provide paddock level detail across regions and therefore provide regional context for local interpretations and actions. Even where new radiometric data must be acquired the method is cheaper to implement than traditional methods and provides much more detailed results.

While there is large room for improvement the radiometrics can provide much better information on soils than previously available at much lower cost. The information provided relates to soil properties such as pH, texture and depth as well as salinity and so aids in developing understanding of the system and in implementing remediation.

Application

EM

Knowledge of the existence of a deep salt store is generally of little benefit except perhaps in irrigation areas. NaCl is highly soluble and its past accumulation means that it is unlikely to move much in the future in dryland situations. Areas are at risk where there is movement of water and these generally do not have particularly high salinity (logically high levels of NaCl cannot occur where there is significant drainage).

New work by the Bureau of Rural Sciences (BRS) identifies that the salt in groundwaters in the SW slopes of NSW is recent in origin and so does not derive from the deep salt stores mapped by airborne EM. This situation was predictable from results published in 1973 and relates to water moving along preferred pathways. Knowing the bulk salinity of the subsoil is generally of no practical value without other information that is very difficult to obtain.

The assertion in the technical review that salinity hazard equates directly with the level of the salt store is used to justify the assertion that EM provides the only appropriate regional mapping method. This is despite the review noting that the occurrence of salinity impacts depends on the composition as well as level of salt. Adverse salinity impacts can occur at low salt levels hence the level of the salt store is not a reliable indicator of hazard or risk. The solution given for salinity mapping in the technical review arises through a definition based on the capabilities of an instrument rather than the requirements.

Such irrationalities reflect an attempt to define salinity as being a single factor that directly relates to a single physical measure. The issues of concern with dryland salinity arise through loss of agricultural production and changes to natural systems in the composition of plants and animals. Salinity can affect these in a variety of ways. Some are direct, as in toxicity and osmotic reduction in water availability, while others are indirect as with changes to soil structure and health.

Toxicity effects can arise through the relative composition of salts as well as their overall level. The broad osmotic effects depend on the level and composition of salts but with a strong interaction with climate. Effects on soil structure depend on the characteristics of the soil as well as the levels and composition of salts. Soils having low levels of total soluble salts but high sodium absorption ratios can be strongly adversely affected by salinity. From our knowledge of the mechanisms whereby salinity produces adverse impacts a measure of the level of salt store alone cannot reliably identify the hazard or risk of dryland salinity.

As well as not reliably identifying risk, the EM does not give any information useful in providing remediation.

Radiometrics

While salinity risk can be difficult to determine it is apparent that most risk is associated with changes to the soil (roughly the surface metre) and that most land use and management also address the soil. Knowledge of the soil is of paramount importance in addressing salinity and information from the radiometrics can greatly improve this knowledge.

The key benefits of the radiometrics are that they:

- Develop knowledge and understanding of the factors causing adverse salinity.
- Provide information essential for effective remediation, namely soils.

While the radiometrics can provide useful information on salinity it is the additional information that allows this to be used to derive benefit. The results address land use and management generally and are not restricted to identifying the occurrence and levels of salts.

The limitations of results from airborne surveys relate to the reliability of regional results at the paddock level. An appropriate method should remove the main sources of ambiguity but there is a very real limit to the spatial resolution that can be achieved that depends on the quality of the survey and the nature of the system being studied. Data from existing airborne radiometric surveys generally (almost invariably) cannot map all of the patterns of variation in soils. Such scaling issues can be addressed by taking ground radiometric measurements, as has to be done with EM, but this greatly increases costs and looses the regional context.

Existing airborne radiometric surveys can provide paddock level detail with regional studies and thereby provide the most scale independent information on soil properties, including salinity, currently available. The cost effective solution is to improve the quality of airborne surveys and information extraction from them. Possibilities include increasing the dimensionality of the analysis by identifying additional radiometric bands.

The current situation is that landholders find the radiometric patterns useful even for radiometric classes that are not statistically significantly different. The mapped patterns are real but the variability associated with regional sampling does not necessarily allow precise labeling of local results. However, the main practical limitation currently relates to education. Such detailed results have not previously been available hence there is a need for education on the means of using the information to derive benefit.

EM Results

Fig. 1 compares results for EM31, which provides a bulk measurement of apparent conductivity (ECa) to a depth of around 6m, and a surface fit to a grid of field soil samples for the 0.4m depth. The main occurrence of salinity in the NW corner is evident on the ground as well as in both results. This occurrence is associated with seepage of saline groundwater exacerbated by irrigation. However, there is essentially no association between results in other parts of the landholding.

High salinity at 0.4m (b) at X is due to poor road drainage while that at Y was likely caused by a leaking irrigation channel. High surface salinity in the SW (Z) likely reflects natural surface drainage. High salinity in the EM in the NE is likely due to application of water in an adjoining landholding and/or subsoil salinity. As salt accumulation at 0.4m has a pronounced affect on land use the EM31 results do not provide a reliable indication of salinity hazard or risk if only because it provides a bulk measurement across a large depth.

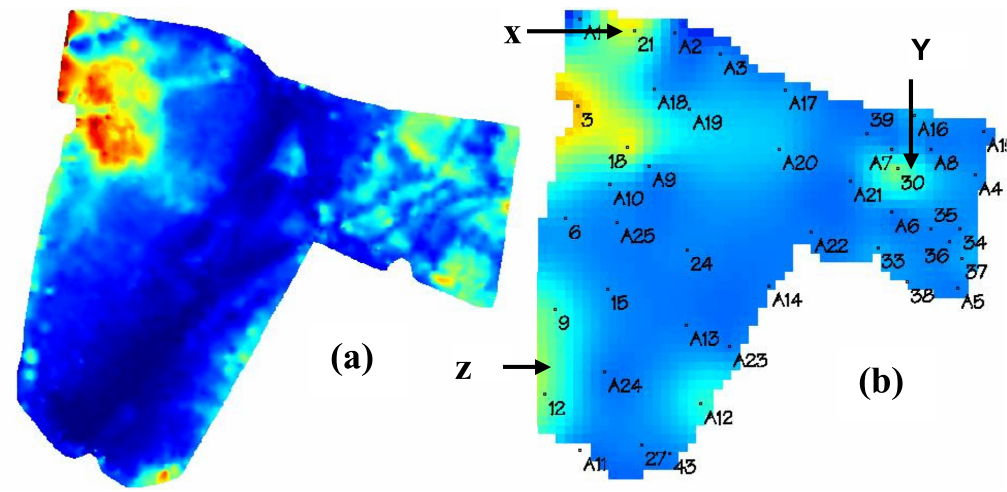

Fig. 1

Surface fitted EM 31 data (a) and soil salinity measured at 40 cm depth (b), for a 200 hectare property at Griffith.

Blue indicates low salinity, red is high.

The main practical difficulty with EM relates to separating effects of salinity from effects of clay and moisture. In one example the EM31 patterns generally reflected natural drainage patterns but the greatest difference was along a fence line separating fallow from pasture. All EM patterns related to moisture and one was associated with land use.

The multi-frequency Tempest EM data provide profile information that aids interpretation (Fig 2[1]) but there is effectively no information for the surface 5m and the reliability of that for the 5-10m layer is uncertain. The coverage of this regional study was around 4,500 km2.

The results in Fig. 2 were calibrated for salinity using observations in boreholes and gave an empirical calibration of around 70%. This level of result is non-limiting but the results still require careful interpretation for application. The high levels of salinity for the 15-20m layer (Fig. 3) represent accumulations in heavy clay that would be expected to be largely immobile due to the very low permeability of such clay to water.

With field observations in deep boreholes some areas of low salinity can be identified as being associated with differences in materials, such as the buried hill, but other areas are identified as

[1] Figs 2 & 3 are Figs 5 & 4 from *Chasing down salt in Australia* by David L Dent and Robert O Braaten, Bureau of Resource Sciences presented at a BRS conference on Emerging Technologies in Australia in July 2000. (on www.brs.gov.au) The Tempest data were flown by Furgo and processed by CSIRO Mineral Exploration.

being pathways for water movement. These pathways for water movement are of most consequence for potential changes associated with dryland salinity. Such pathways are not distinctive in the EM as they do not have high salinity and their identification depends on having good ancillary information. The benefits of the EM lie in improving the targeting of field sampling and providing mapping (spatial extrapolation) once the characteristics of the features that can be recognised in the results are known.

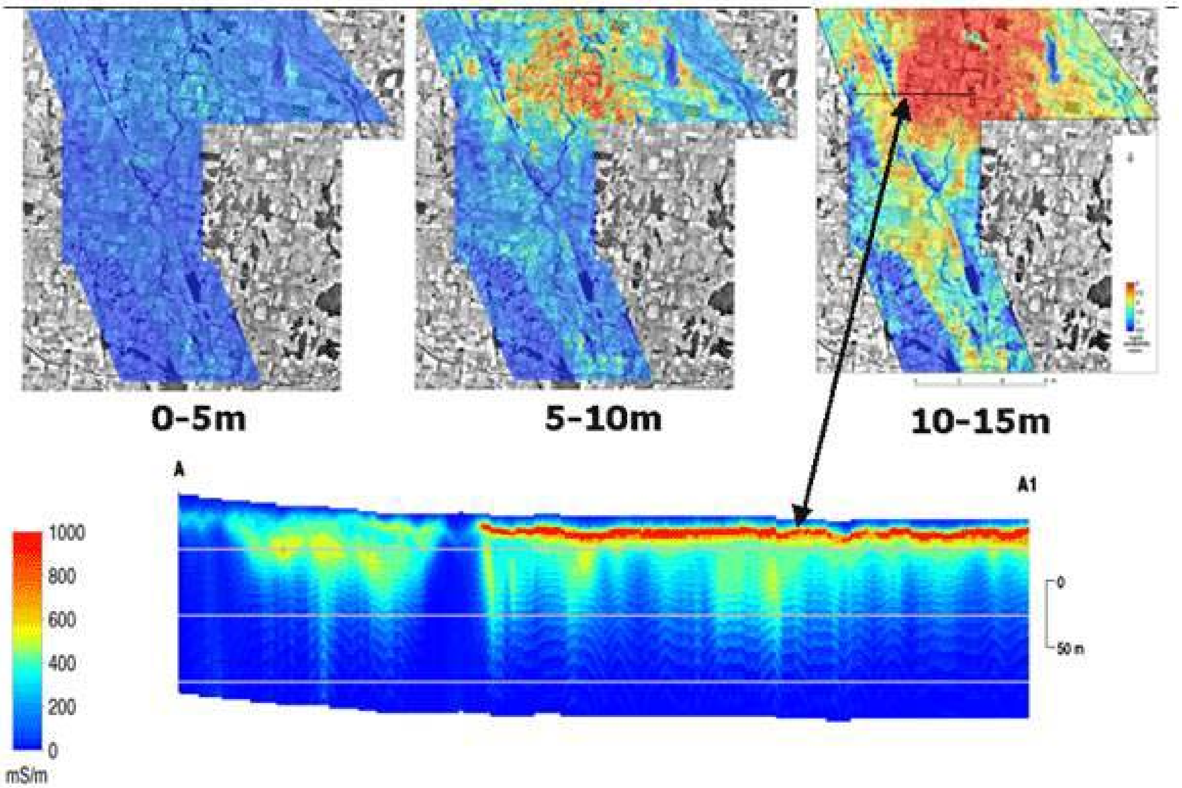

Fig. 2 Electrical conductivity (EC) for different depth increments and a cross section for a regional survey of Tempest multi-frequency airborne EM data. EC determined by empirical correlation of field samples with the apparent conductivity (ECa) estimated from the EM measurement. Survey area approximately 4,500km^2.

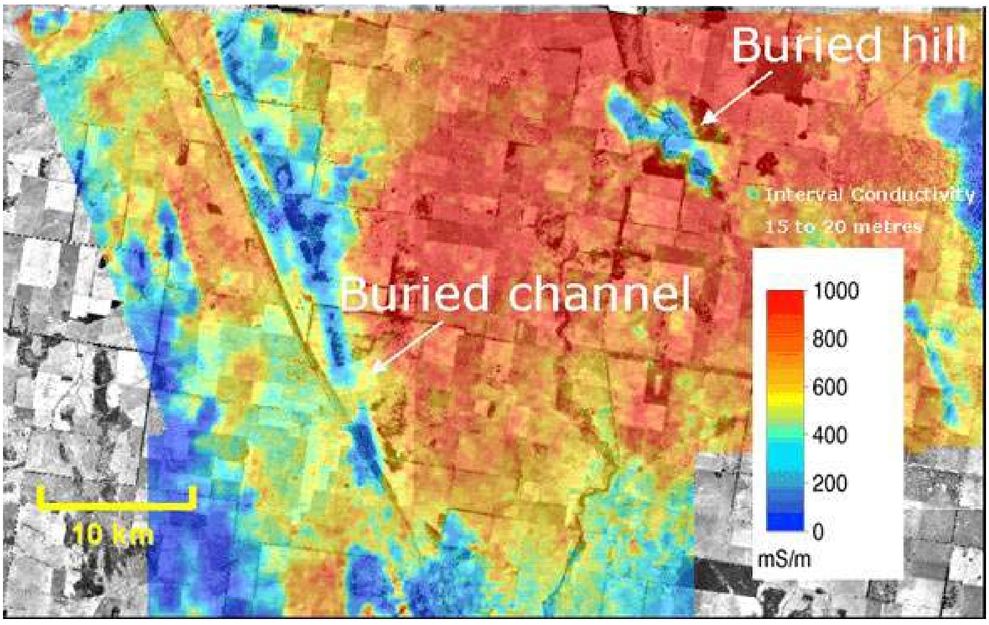

Fig. 3 Detailed map of the electrical conductivity (EC) for the 15-20m depth increment for part of the survey presented in Fig. 2.

Radiometric Results

The size of the region covered by the airborne radiometrics for the Cootamundra Shire, around 90 x 60km, is slightly larger than for the Tempest survey in Fig. 2. The radiometric classification identifies the overall patterns of soils (Fig. 4) and field sampling is used to identify the soil properties associated with each class. Grouping classes with similar levels of salinity provides a regional soil salinity map (Fig. 5).

The strength of relationships between radiometric classes and soil properties differs with the quality of the survey, the nature of the system, and the particular soil property. Relationships are generally best for texture, pH and pe/pH (pe is oxidation reduction potential expressed as a concentration) of the A2 and B2 horizons. Salinity often shows highest variability.

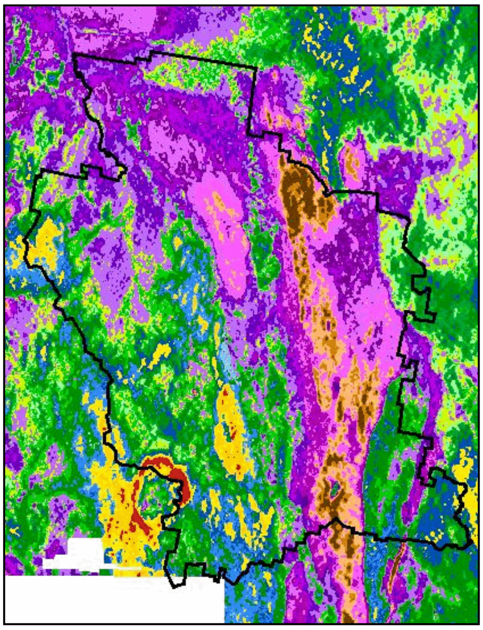

Fig. 4 Radiometric classes showing patterns of soil variation, Cootamundra Shire.

In the depositional Jemalong-Wyldes Plains one group of classes consistently had low salinity, another group moderate to high salinity while a third group could have low or high salinity. Theoretically this situation indicates changes to salinity associated with land use.

The impacts of salt depend on the composition as well as level as with clay dispersing at high sodium absorption ratios even at low salinity levels. Patterns for the dispersibility of the B horizon (Fig. 6) differ from salinity hence the risks associated with salinity cannot be determined by knowledge of the levels of salt store alone.

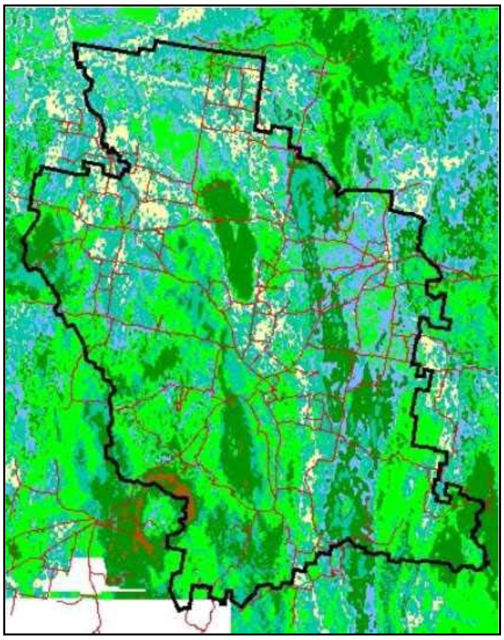

Fig. 5 Salinity (ECe) of the B2 horizon, Cootamundra Shire. Yellow > 0.9 dSm^{-1} Lime 0.6-0.9 dSm^{-1}, Blue-greens 0.1 - 0.3 dSm^{-1}.

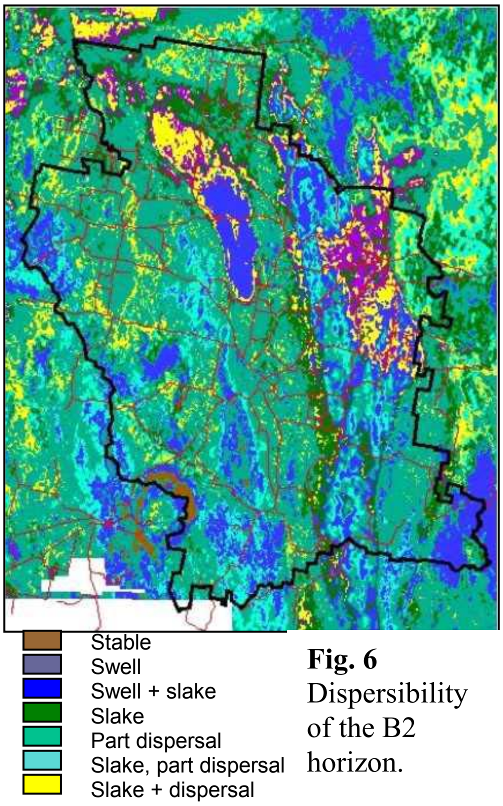

Fig. 6 Dispersibility of the B2 horizon.

None of the soils in the Cootamundra Shire have particularly high salinity but some areas have accumulations of salt. Figure 7 maps areas with highest salinity for Cootamundra and such results for part of the Shire (Fig. 8) identify three forms of expression of salinity: accumulations around a drainage line (left side), seepage at the break of slope (central circular feature), and along a fault line (right side). Patterns associated with fault lines run for up to 100km and cut across the Murrumbidgee and Lauchlan River basins. Other forms of salinity expression in the region occur where fault lines exit from hills onto the plains (the salinity fans out) and at geological unconformities other than fault lines (e.g. boundaries between formations).

Salt accumulations along fault lines and the break of slope are not associated with rising groundwater. Moreover, the simplest explanation for the salinity associated with the stream line is accumulation through surficial lateral flow. The detailed salinity mapping provides information not previously available and hence improves understanding of the processes involved in dryland salinity.

The results in Fig. 9 identified that annual damage to a stretch of the Olympic Highway arose through its location on a salinity pathway. The existence of the salinity was previously known but the reason for its existence was not. These results allowed implementation of permanent repairs.

Fig. 10 illustrates that the paddock level detail in the regional salinity mapping was confirmed by ground EM salinity observations by others. The reliability of this comparison depends on the salinity having deep as well as surficial expression which would be expected to arise with fault lines.

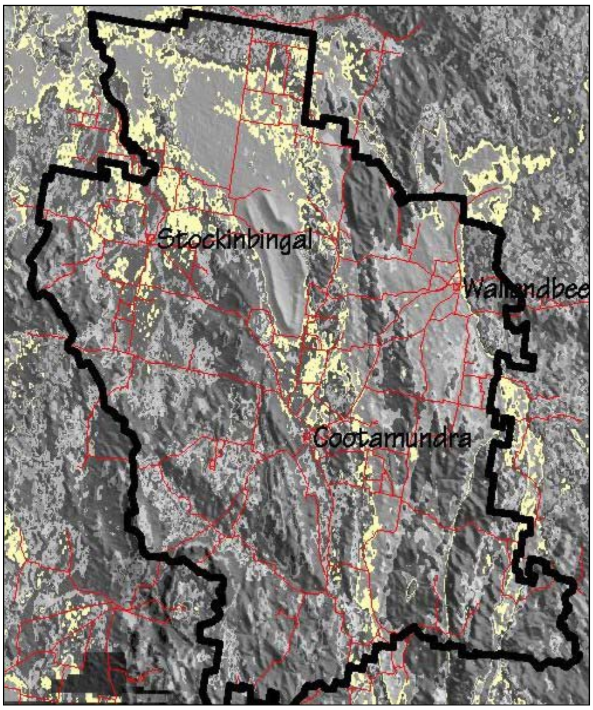

Fig. 7 Areas of high surface soil salinity in the Cootamundra Shire (salinity risk & salinity pathways)

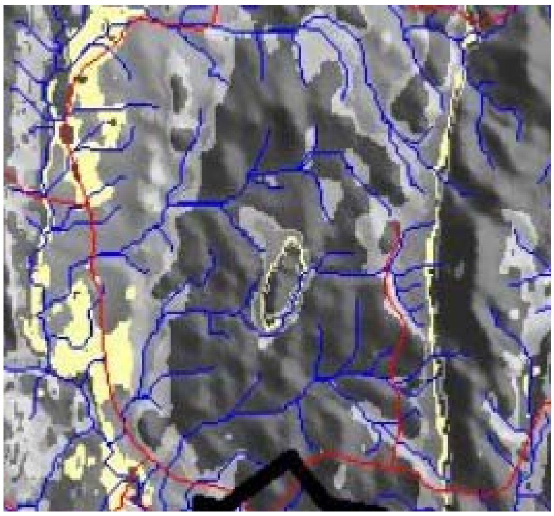

Fig. 8 Patterns of salt flow and accumulation in the Cootamundra Shire.
a Along flats and streams
b Break of slope around hills
c Along fractures and fault lines

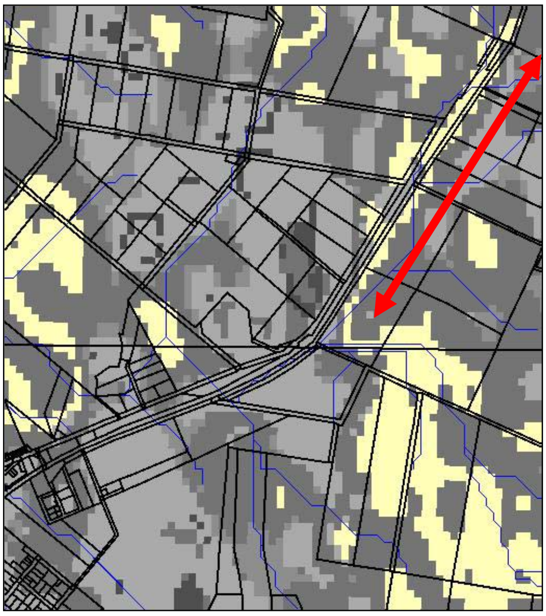

Fig. 9 Section of the Olympic Highway subject to annual repairs (associated with a salinity pathway).

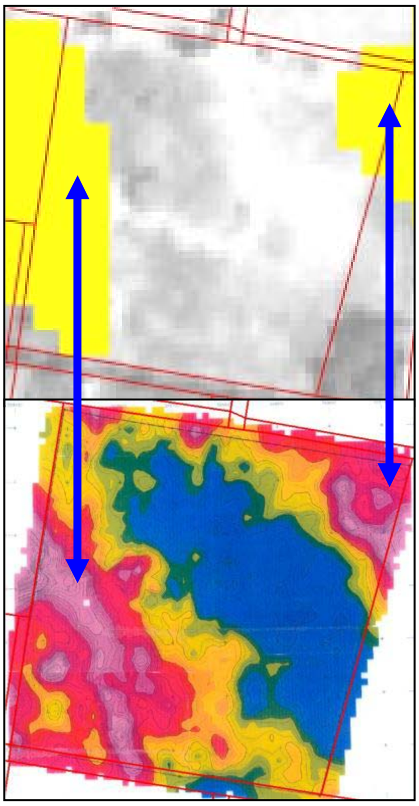

Fig. 10 Comparison of a salinity class (top) and EM31 results (bottom) for an individual landholding.

Extrapolating Radiometric Salinity Results

The relationships between soil properties such as salinity and the radiometric classes as illustrated for Cootamundra can only be expected to be valid within the range of observations as they are derived through empirical correlations. However, the high salinity classes were extrapolated to adjoining shires and across different radiometric surveys. For this to occur there must be a distinct spectral signature in the radiometrics associated with the salinity.

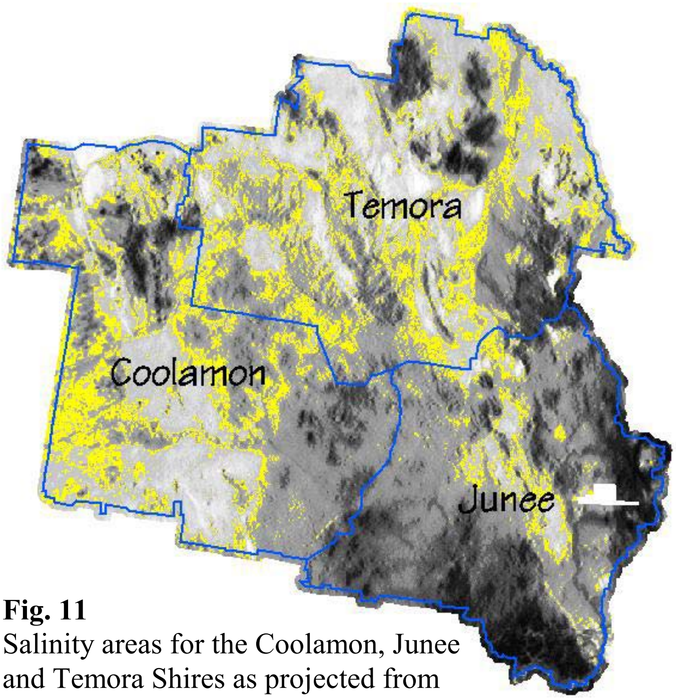

Fig. 11
Salinity areas for the Coolamon, Junee and Temora Shires as projected from the Cootamundra results.

Figure 11 illustrates extrapolation of the salinity classes for Cootamundra across adjoining shires. The western boundary of the Cootamundra Shire abuts the E and SE parts of the mapped area. Figure 12 is a zoom in for part of the Temora Shire.

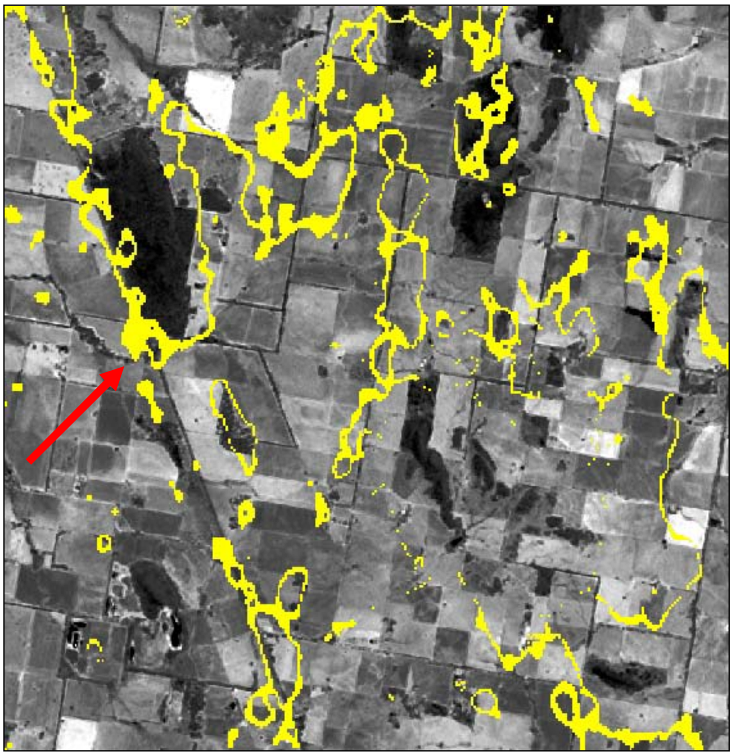

Fig. 12 Salinity pathways in Temora projected from Cootamundra. Satellite image background.

Fig. 12 shows fine spatial pattern associated with drainage similarly to Fig. 8. There is no apparent degradation of the spatial detail which would be expected if identification of the salinity class depended solely on empirical correlation. Salinity is associated with surface drainage lines that meander in the flat terrain, seepage lines at the break of slope around low hills, and road side drains.

In the central west a road diverts the salinity class from the natural streamline (red arrow). This indicates a reasonably short persistence of the salinity signature: it is too short to be associated with soil development. This, and the independence of the salinity class from the surrounding geology, effectively precludes the salinity signature deriving from K, U and Th in the parent material.

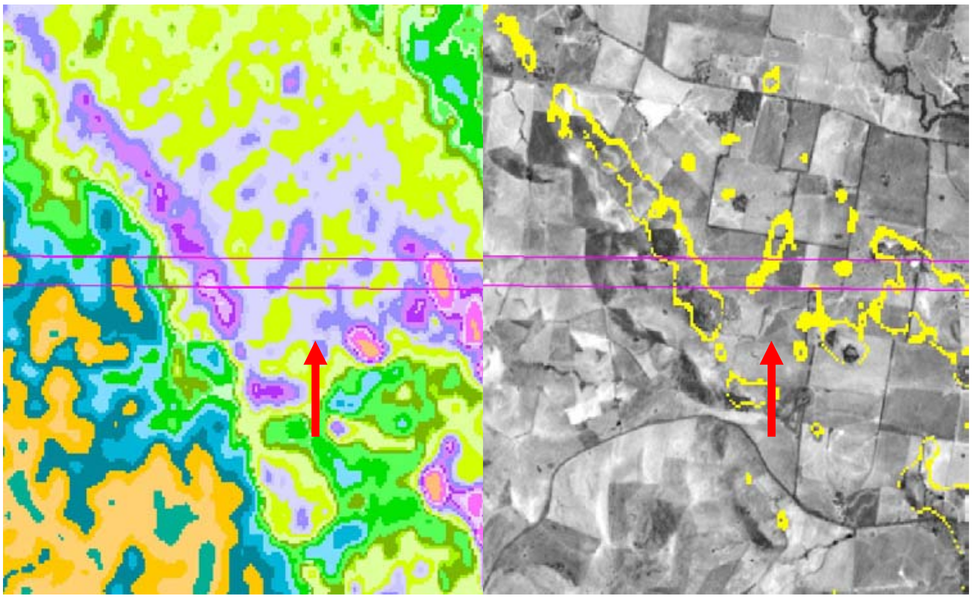

Fig. 13

Extrapolation of the Cootamundra radiometric classes to adjoining areas and across surveys.

The purple horizontal lines identify the nominal survey boundaries. The arrows identify the actual survey boundary.

The results in Fig. 11 incorporate two radiometric surveys additional to that covering the Cootamundra Shire. Figure 13 maps all radiometric classes across the boundary of two surveys and highlights the salinity class. The radiometric patterns are consistent across surveys hence the surveys provide the same information. Despite the consistent patterns the match between most classes is generally only around 50% reflecting the difficulty of spectrally matching radiometric surveys. However, the match for the salinity class is much higher at around 90%. This ability to extrapolate salinity classes across surveys would not be expected from the prior understanding of the radiometric measurement and would not arise if the result depended purely on empirical correlation.

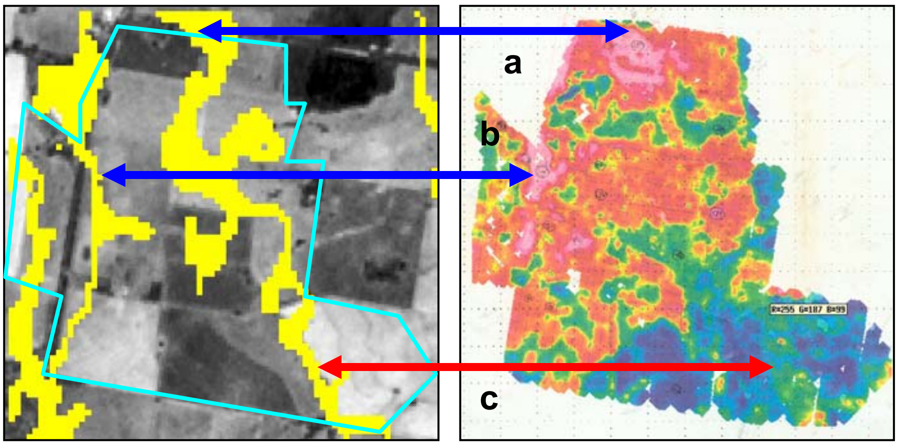

Fig. 14

Comparison of a salinity class and EM31 results for Temora. Blue arrows link previously known saline areas.

Figure 14 compares the extrapolated salinity class with EM31 results for a Temora landholding. While several areas of high salinity were previously known (a, b) the pathways for salt movement were not (particularly c). The radiometric results provided additional information to EM that is invaluable when addressing remediation and land management.

The extrapolated salinity class appears to map surficial salinity whereas the EM31 provides a bulk measure to 6m. Also, the EM provides a measure of the level of salinity whereas the **extrapolated** salinity class identifies the presence of significant salinity but does identify its level (the extrapolated result is categorical). The potential benefits of the extrapolated salinity class relate to the ability to map surficial patterns of drainage of salt and to monitor changes associated with land use and remediation.

Radiometric Example Without Field Sampling

Results in Fig. 15 are for the Dicks Creek area near Yass which has long been held as an example of adverse salinity caused by rising groundwater. Comparison of the classified radiometrics and the occurrence of salinity scalds in optical satellite imagery identifies that the adverse salinity occurs in a distinct radiometric class located along the boundary between two geological formations. The same conclusion was reached by Graham Taylor through analysis of airborne hyper-spectral imagery and field observation. Due to the occurrence of quartz veins Taylor concluded that some structural features determining the occurrence of surficial salinity were very old.

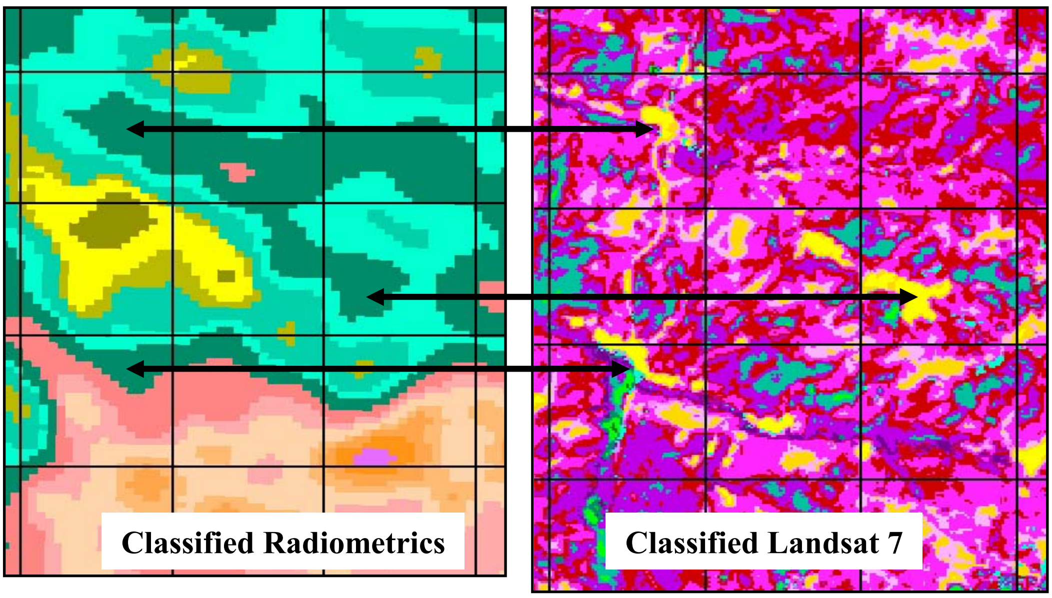

Fig. 15

Classified airborne gamma radiation data and satellite image for the Yass region.

Salt scalds are bright yellow in the satellite image. Kilometre grid

DISCUSSION

The results presented here for the EM and airborne radiometrics accord with basic theoretical considerations, the radiometric salinity signature excepted. EM is presented as a one dimensional measurement and is significantly affected by a number of factors that vary in the environment. The measurement is strongly scale dependent in the x, y and z dimensions. The measurement is simple to obtain but often difficult to interpret because the information is limited to one variable that is affected by a number of factors.

The radiometrics are a complex multi-dimensional measurement primarily affected by two factors. They are strongly scale dependent in the x and y but not the z dimension giving a significant degree of scale independence. The measurement is difficult to obtain and analyse but contains a considerable amount of information relevant to dryland salinity. With appropriate analysis the radiometrics can provide a large amount of information useful for addressing dryland salinity. Appropriate presentation of results makes them readily interpretable and applicable to land management generally.

The information presented here on radiometrics for all except the radiometric salinity signature has been freely available for many years through being used for marketing on company web sites. Environmental Research and Information Consortium Pty Ltd (ERIC) provided the development and service delivery over many years and the innovation won many awards in open competition. The application notes, product sheets and papers that were available contained much more detail than this report. The issue is why the technical review denies a demonstrated capability that has long been successfully delivered commercially while strongly promoting one with much lower potential and applicability.

The comment in the technical review that some claims by vendors as to the applicability of radiometrics in mapping salinity have no basis in science relates to the identification of a distinct salinity class having a consistent spectral signature. They suggest that the results illustrated in figures 11 through 14 cannot be achieved. Their conclusion is based on the results of unpublished theoretical modeling by others identifying that levels of cosmogenic ^{24}Na cannot be detected in airborne measurements.

The radiometric signature for the distinct salinity class, as mapped in figures 7 through 14, is completely independent of geology when the signatures for all other classes are not. There is a distinct salinity class that is independent of geology that has a distinct spectral signature that can be extrapolated across surveys. Such observations represent fact and cannot be negated by any theoretical modeling.

Rationally the issue is not whether a distinct salinity signature exists but how it comes about. The most plausible explanation (hypothesis) is that it derives from cosmogenic ^{24}Na because this radionuclide has two of its multiple emission peaks located in the bands used for K and Th in airborne surveys. The difficulty, as illustrated by the modeling, relates to the expected very low level of any such signal. While there is no proof positive either way, the form of analysis used to produce the salinity results from radiometrics technically has the potential to resolve distinctive signatures well below the threshold of signal to noise. The modeling does not disprove the hypothesis because of the inapplicability of assumptions invoked in applying the model results.

Those denying a link between the salinity signature and ^{24}Na suggest that the consistent signature arises through a fortuitous correlation with K, U and Th in the parent materials. Given the complexity of the geology, the dependence of all other classes on geology, and the ability to extrapolate the class across regions and surveys, this explanation is grossly deficient. It is further deficient because the signature does not have the temporal persistence of a signal that would derive from K, U and Th in the parent materials. The ‘explanation’ that the results arise by chance serves only to identify an inability to provide a plausible explanation for results they are not capable of achieving.

The observation of a distinct radiometric class that is independent of geology cannot be refuted. The observation that this class relates to salinity has observational support and has not been refuted. The hypothesis that the signature derives from ^{24}Na has yet to be tested but has not been refuted by the modeling conducted in the review. The adverse assertions in the technical review are therefore contrary to what would be concluded with application of the scientific method. The assertions derive from an extrapolation of the capabilities of existing technology rather than scientific analysis.

This situation is well illustrated by the quote from Popper given below.

> *Although no scientific theory as such can directly encourage activity (it can only discourage certain activities as being unrealistic), it can, by implication give encouragement to those who feel that they ought to do something. Popper, K. (1957). The poverty of historicism. Routledge and Kegan, London.*

This book by Popper addresses the futility of attempting to predict the future from the past which is what was attempted with the modeling of the ^{24}Na signal in the review. The first and second points in the quote identify that one does what one can do with that knowledge serving to suppress the investigation of alternatives. The third point reflects the human need to be seen to be doing something which, given the first two points, generally means doing more of the same (variations on a theme).

The means identified to resolve a problem reflect the knowledge and capabilities of the respondent. Individuals and hence organisations almost invariably identify that the solution lies in increasing the level of existing activities when a problem logically should not exist if the existing activities were appropriate. The persistence of a problem means that current activities are inappropriate and that new approaches are necessary. The issues for research are how to gain support for the conduct of anything different or new and then how to gain acceptance of results in the face of the enormous inertia. This situation has been compounded in this instance by the results deriving from industry rather than organisations claiming traditional rights to the territory.

While this note addresses some major misrepresentations in the technical review it does not address all significant issues, even for EM and radiometrics. The technical review contains the illogicality that EM is identified as being both a direct and indirect measure of salinity and the spurious claim that radiometrics are not applicable in depositional (sedimentary) areas. Radiometrics are said to be limited by results depending on empirical correlation but there is no mention that such empirical correlation is also needed to convert the apparent conductivities (ECa) provided by EM into measures of soil salt stores the review suggests it provides. However, the main overall deficiency is that the review does not assess the value of different technologies in addressing dryland salinity and only advises others how they might do it. Even then it does not provide a reliable basis for such an evaluation as the technical assessment of methods is based on the depth of signal generation rather than the depth for which useful information can be derived.

For some measurements the depth range is greatly exaggerated, even for signal generation, as with the suggestion that magnetics can provide information on the surface through to bedrock.

The value of magnetics lies in addressing deep subsurface structure. Airborne EM is said to address the surface through to bedrock when the shallowest depth given for extraction of information identified in the report is 5 to 10m which is well below the root zone. Any surface information in airborne EM derives from infrastructure such as power lines and so represents confounding when addressing salinity. The depth range for radiometrics has been minimised by suggesting that the measurement can only provide information for the surface tens of centimeters where this is apparently designed to minimise its perceived value.

Other significant issues with the technical review relate to the assessment being based on acceptance of the rising groundwater model as being the general model for dryland salinity, and the assessment of the level of salinity hazard. The detailed examination of the nature of hazard and risk in the review implicitly identifies hazard as being categorical. It exists or it does not for a particular attribute, such as for salinity, frost or flood, but does not have a level. Risk addresses level but can only be assessed for very well defined circumstances. Hazard identifies that a potential exists while risk identifies the level of that potential.

Accumulations of salt exist in most arid and semi-arid areas of Australia hence these areas can potentially have a salinity hazard. Mapping the occurrence of a salinity hazard could be a trivial exercise[2] and the key issue relates to the assessment of risk. The rationale for the assessment of the level of hazard in the review is undefined and obscure hence the assessment has limited value.

The assertion that the mapping requirement relates to the level of salt store largely derives from acceptance of the rising groundwater model. The technical review states that:

> *It is worth noting that dryland salinity is a problem associated with increased water supply in salty landscapes.*

This situation is common in Australian irrigation areas. However, water supply represents an input and, while dryland agriculture can change the partitioning of water between different components in the hydrological water balance, by definition it cannot change the inputs.

The above statement is further illogical as the technical review discriminates between primary and secondary salinity. Primary salinity is natural and secondary salinity is land use induced. For a landscape to initially be salty there must have been primary dryland salinity. The statement in the review is therefore illogical except where dryland salinity is defined as only arising through the impacts of human land use when all dryland salinity becomes secondary by definition. There cannot be primary dryland salinity for this statement to be rational.

Overall, the assessments of mapping methods in the technical review are generally inapplicable because of the invalidity of assumptions that have been invoked as to the model for dryland salinity, the depth for the derived information, the nature of a hazard, and the need relating solely to the level of salt stores. For radiometrics this has been compounded by a failure of those conducting the review to accept results they cannot produce.

The process used to produce the technical review was identified as being designed to keep the recommendations at arms length from those controlling the disbursement of salinity research funds and to ensure that the recommendations were scientifically sound. However, the notion of independence is false as the review was effectively conducted by those traditionally

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[2] The assessment of hazard depends on the land use as well as the occurrence of salt hence there need be no single or unique answer. Land use has generally taken natural occurrences of salinity into account hence while salt exists it need not represent a hazard. However, the salinity could represent a hazard if an alternate land use was considered. Salinity would not be a hazard with appropriate grazing of saltbush plains but would be if irrigation was introduced. There is a need to clearly define the boundary conditions.

receiving the funds. The effective conclusion that all current methods bar those from industry are appropriate prevents competition for these established interests. There were no speakers from industry at the public presentation at the Academy of Science despite repeated requests for this to occur.

The question of the soundness of the science is similarly answered by the technical review being controlled by those benefiting from the recommendations. However, even this does not explain the existence of logical errors.

Addressing key conclusions in the technical report given in the introduction here it can be identified that:

1. Information on the level of the salt store alone is inadequate for addressing dryland salinity. This is illustrated by results for EM and from radiometrics, quite apart from being an essential conclusion from any analysis of the effects of salinity.
2. Mapping of regional subsurface salt stores, the key recommendation of Spies and Woodgate, would not identify or address the main salinity issues in the Cootamundra region or most other areas and therefore cannot provide a solution, strategic or otherwise.
3. Given point 1, EM alone cannot adequately address salinity and its application is further limited by difficulties in determining what the measurement is reflecting. EM can be useful but only in conjunction with considerable additional information.
4. The rising groundwater model is generally inapplicable to dryland salinity in the Cootamundra region and is identified as a special case of a more general model in the House of Representatives salinity report. The basis of assessment of methods for addressing salinity hazard in the technical review would generally be invalid.
5. Radiometrics have been used to provide regional soil maps for over 10 years, and to map soil salinity, with the results being used to provide benefit.
6. The assertion in the review that claims made by vendors as to the capability of radiometrics for salinity mapping have no basis in science is incorrect.

The technical report is presented as being the reference or standard for mapping to address dryland salinity in Australia and has been endorsed by the Academy of Science and the Academy of Technological Science and Engineering. It is meant to inform consumers such as catchment management groups as to the appropriate means of obtaining salinity information. This has significant commercial, social and environmental implications given the level of funding allocated to such purposes by the Commonwealth Government.

The deficiencies in the report by way of fact and logic have led to the presentation of conclusions and recommendations that mislead the consumers it is meant to inform. The technical report is highly defective for purpose and should therefore be withdrawn. Moreover, the report serves to greatly suppress industry involvement as it specifically denigrates work by industry and recommends that industry proposals be vetted by public organisations.

In being positive to current activities by publicly funded organisations that helped compile the report it seeks to retain the control and use of salinity funds by public organisations and prevent competition from industry. This evidences an urgent need to develop an administrative structure that prevents public organisations from blocking industry delivering services to achieve cost efficiencies and promote industry development. Expanding public expenditures without industry development is not sustainable.

The House of Representatives salinity inquiry arose from a perception that expenditures on dryland salinity were not being effective. Salinity research has been a Commonwealth Government priority for over 25 years but the situation is now predicted by public scientists to become worse before it begins to get better. The call is for increased research funding but with the only promise being that any benefits can only be realised in the long term.

The persistence of a problem evidences deficiencies in existing solutions and activities. The issue is how to achieve change in the face of the inertia driving from established interests seeking to maintain the status quo. The recommendation in the House of Representatives report to involve industry in public R&D addresses this issue. It provides an automatic mechanism for aligning work to the needs of the intended beneficiaries as well as helping ensure the availability of necessary support services. It provides a mechanism for realigning research so that it better addresses community needs.